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Changes in Tree Growth Rates in Vermont

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ABSTRACT

At three separate times (1965, 1973, and 1983) over 2,300 trees were measured at various locations throughout Vermont. For 19 species or species groups, average annual basal area growth in 1965-72 was compared with that in 1973-83. Basal area growth of two species, red spruce and white spruce, declined significantly. Growth of several species, such as balsam fir, paper birch, and quaking aspen warrant further study. For 11 species or species groups, basal area growth rates improved over the same period.

Keywords: Picea rubens, Picea glauca, growth decline, basal area growth.

Introduction

The issue of regional air pollution in the United States has raised concerns about the growth and composition of the Nation's forests (Smith 1985). Are the forests undergoing declines or changes in growth that may be associated with airborne pollutants? This is a two-part question. Part one concerns decline or growth loss, while part two deals with mechanism – cause and effect.

The recently completed forest survey of Vermont (Frieswyk 1985) provided an opportunity to evaluate the first part of this question for an entire State. Diameters were measured in 1965, 1973, and 1983 on 2,387 trees growing in forest stands at 435 locations across the State. This Note presents estimates and standard errors of the differences in average annual basal area growth between the measurement period 1965-72 and 1973-83 for 19 tree species or species groups. The statistics are used to test the hypothesis that there was no difference in the average annual basal area growth rate for the two periods. Results of the test will be used to identify candidates for further evaluation, including cause-effect studies.

Background

Many studies on the effects of air pollution on trees have focused on diameter growth rates. Previous diameters are relatively easy to obtain by using an increment borer to extract a core from the bark to the center of the tree. The annual growth rings can be measured to determine diameters of the tree at various points in its life. The casual observer can readily see that the width of annual rings decreases as a tree ages and its diameter increases. This natural decrease can confound the determination of man-caused effects.

Analysis of basal area growth should avoid this problem (Phipps 1984). The basal area of a tree is defined as the cross-sectional area of the stem at breast height (4.5 feet above the ground). Basal area varies with the square of the diameter at breast height (d.b.h.). Spurr (1952) states that "basal area per tree may be assumed to increase at approximately a constant rate" for dominant and codominant trees in immature forest stands. This relationship is not expected to hold when a tree is in the juvenile or overmature stages. Assmann (1970), however, states that basal area growth has a bell-shaped distribution which is skewed to the left. It is similar in shape to the diameter growth curve but peaks 10 to 20 years later.

Methods

Some 2,387 trees were measured on 435 USDA Forest Service Forest Inventory and Analysis plots

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that represent a variety of commercial forest conditions in Vermont. Trees were first measured in 1965 and remeasured in 1972 and 1983. Diameter at breast height (to the nearest tenth inch) was recorded for trees over 5 inches in diameter. Sample trees were selected by one of two rules: probability proportional to frequency, or probability proportional to basal area. Only live trees that were measured on all three survey dates were included in this analysis. Trees that grew larger that the 5-inch threshold during the first period were excluded from this analysis. Trees that died during either period also were excluded, because they were not considered to be representative of the growth rates. Because other tree and stand characteristics are not available for the first survey data, they could not be included in the analysis. The data are summarized in table 1.

In a paired *t*-test, we analyzed the differences in average annual basal area growth rates for the two periods for equality with zero. The average annual basal area growth per tree for the first period was computed as:

$$BAG_{1\text{-}2} = 0.005454\ (D_2^2 - D_1^2)/t_{1\text{-}2} \qquad (1)$$

where:

$BAG_{1\text{-}2}$ = average annual basal area growth (in ft^2/year)

D_m = diameter at breast height (in inches) at beginning of measurement period m ($m = 1,2$)

$t_{1\text{-}2}$ = period between measurements 1 and 2 (in years)

The second-period growth rate, $BAG_{2\text{-}3}$, was similarly defined.

The statistics of interest are the basal area growth rates, $BAG_{1\text{-}2}$ and $BAG_{2\text{-}3}$, and the difference of the basal area growth rates:

$$d = BAG_{2\text{-}3} - BAG_{1\text{-}2} \qquad (2)$$

The hypothesis that there was no change in growth rates was tested.

The second analysis used the diameter at the beginning of the second measurement period, D_2, as a covariate. In uneven-aged stands of trees, diameter has been found to explain some of the variability in the estimates of basal area growth, because it represents in part the relative position of trees in the forest canopy (Gibbs 1969). Plots of d against D_2 showed (1) that the relationship between d and D_2 was linear, (2) that the slopes appeared to be zero for some species, and (3) that the variability in d increased linearly with D_2. A linear relationship between d and D_2 suggested that a simple linear regression model was appropriate. Non-homogeneous variance suggested that weighted regression techniques be used. Weights equal to the reciprocal of $(D_2\text{-}5)$ were found to be appropriate. The model used was:

$$d_i = a + b\ (D_{2i} - 5) + e_i \qquad (3)$$

where:

a = expected value of d at $D_2 = 5$

b = slope

e_i = error term with expected value of zero

Results

White spruce and red spruce were the only species for which the average annual basal area growth rates of survivor trees decreased (table 2). The mean differences for seven of the species were not significantly different from zero. The decreased growth rate of white spruce, which grows in association with red spruce, is probably real. However, the sample size for white spruce ($n = 25$) is too small to show statistically significant differences. The sample sizes for black cherry ($n = 20$) and other softwoods ($n = 9$) are also quite small. For 11 of the 19 species, annual basal area growth was higher in 1973-83 than in 1965-72. No significant change in growth rate was found for balsam fir, paper birch, hophornbeam, and quaking aspen, or for other softwoods and hardwoods not listed in table 2.

The covariate, D_2, was statistically significant for 12 of the species. For all species except white spruce, either parameter a or b was found to be not significantly different from zero. When the intercept (a) was found to be not statistically significant, it was set at zero and the slope was recomputed. If the slope (b) was not significantly different from zero, it was set at zero and the sample mean was taken as d. Thus, there were three models: (1) $d = b$, (2) $d = a$, and (3) $D = a + b\ (D_2\text{-}5)$. The parameter estimates and their standard errors are given in table 3.

For both red and white spruce, the growth rate decreased as tree diameter increased. Because white spruce had a positive value of a, small trees had increasing growth rates and large trees had declining growth rates, while trees near 10 inches in d.b.h. exhibited no change in growth rate. The decline in growth rate for larger diameters for the spruces was in sharp contrast to the increase found for 10 of the species. The other seven species or species groups showed no trend.

Conclusions

The results should be interpreted cautiously. The only explanatory variable used was diameter. Factors that affect tree growth, such as competition, slope, aspect, elevation, climate, and soils, could not be considered in this study. We simply assumed that these factors were comparable over both periods. As stated in the introduction, the purpose of this paper is only to identify species where further study is desirable.

Generally, tree growth did not decline during the periods evaluated. For all but two species, basal area growth rates remained the same or increased. Statistically significant increases in basal area growth were observed in 11 species, including three softwood species: eastern white pine, northern white cedar, and eastern hemlock. Six species or species groups showed no statistically significant change in basal area growth: balsam fir, other softwoods, paper birch, hophornbeam, quaking aspen, and other hardwoods.

The 1960's and early 1970's were characterized by severe droughts. The improvements in basal area growth rates for the 11 species could be explained by an improvement in climatic conditions. The short-lived nature of balsam fir, paper birch, and quaking aspen could explain their failure to respond to improved moisture conditions. During the 18-year study period, many trees of these short-lived species may have been reaching overmaturity. However, overmaturity does not explain the decline in growth of spruces, which are long-lived species.

In any case, this analysis was not intended to identify causes. Our results show that, across an entire State, the growth of two important tree species was less in 1973-82 than in 1965-72. Growth of three other species, although not declining, did not increase as it did for the majority of the species. We recommend further investigation into the growth patterns of five species:

- red spruce
- white spruce
- balsam fir
- paper birch
- quaking aspen

This investigation should concentrate on growth factors whose influence is regional in impact rather than site specific. Among such causes are temperature, drought, insect and disease attacks, and regional air pollutants.

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Table 1.--Average and range in diameters of sample trees, by species, for Vermont in 1972

Species	Diameter			Sample size
	Average	Minimum	Maximum	
	- - - - - - Inches - - - - - -			Number
Softwoods:				
Balsam fir (Abies balsamae (L.) Mill.)	7.8	5.3	13.2	103
White spruce (Picea glauca (Moench) Voss)	11.6	6.1	21.5	25
Red spruce (Picea rubens Sarg.)	9.3	5.2	17.6	106
White pine (Pinus spp.)	12.0	5.5	34.6	116
Northern white-cedar (Thuja occidentalis L.)	8.6	5.5	15.1	48
Hemlock (Tsuga spp.)	9.6	5.1	27.0	310
Other softwoods	11.8	6.2	17.1	9
Hardwoods:				
Red maple (Acer rubrum L.)	9.9	5.1	28.5	255
Sugar maple (Acer saccharum Marsh.)	10.8	5.1	41.0	523
Yellow birch (Betula alleghaniensis Britton)	10.8	5.3	29.1	169
Paper birch (Betula papyrifera Marsh.)	9.6	5.5	26.8	172
Beech (Fagus spp.)	10.7	5.1	24.6	156
Ash (Fraxinus spp.)	11.4	5.7	30.0	53
Hophornbeam (Ostyra spp.)	8.1	5.8	18.2	38
Bigtooth aspen (Populus grandidentata Michx.)	9.8	5.6	16.8	37
Quaking aspen (Populus tremuloides Michx.)	9.1	5.5	24.5	62
Black cherry (Prunus serotina Ehrh.)	9.9	5.2	15.3	20
Red oak (Quercus spp.)	13.3	6.0	54.0	76
Other hardwoods	9.7	5.2	20.5	89

Table 2.--Differences in average annual basal area growth rates of survivor trees (1965-72 minus 1973-83) for 19 species in Vermont

Species	Average difference ($\bar{d}$)	Standard error $s(\bar{d})$	Significance level
	- - - - - - - - ft^2/yr - - - - - - - -		
Softwoods:			
Balsam fir (*Abies balsamae* (L.) Mill.)	0.00216	0.00394	0.564
White spruce (*Picea glauca* (Moench) Voss)	-0.00226	0.00943	.242
Red spruce (*Picea rubens* Sarg.)	-0.00130	0.00474	.006*
White pine (*Pinus* spp.)	0.00422	0.01394	.001*
Northern white-cedar (*Thuja occidentalis* L.)	0.00322	0.00577	.001*
Hemlock (*Tsuga* spp.)	0.00180	0.00642	.001*
Other softwoods	0.00285	0.00372	.051
Hardwoods:			
Red maple (*Acer rubrum* L.)	0.00262	0.00933	.001*
Sugar maple (*Acer saccharum* Marsh.)	0.00234	0.00849	.001*
Yellow birch (*Betula alleghaniensis* Britton)	0.00226	0.00966	.003*
Paper birch (*Betula papyrifera* Marsh.)	0.00041	0.00477	.261
Beech (*Fagus* spp.)	0.00238	0.00719	.001*
Ash (*Fraxinus* spp.)	0.00565	0.00853	.001*
Hophornbeam (*Ostyra* spp.)	0.00132	0.00419	.059
Bigtooth aspen (*Populus grandidentata* Michx.)	0.00319	0.00639	.004*
Quaking aspen (*Populus tremuloides* Michx.)	0.00120	0.00827	.258
Black cherry (*Prunus serotina* Ehrh.)	0.00609	0.00580	.001*
Red oak (*Quercus* spp.)	0.00736	0.01828	.001*
Other hardwoods	0.00125	0.00603	.053

*Value differs significantly from 0. The critical probability value for 19 simultaneous tests is 0.006.

Table 3.--Statistics for the simple linear model for the difference (d) in average annual basal area growth rate for the years 1965-72 and 1973-83 by species in Vermont[1]

Species	Estimate of (a)	Std. error (a)	Slope (b)	Std. error (b)
Softwoods:				
Balsam fir (*Abies balsamae* (L.) Mill.)	0.00022	0.00394	0.0	0.0
White spruce (*Picea glauca* (Moench) Voss)	0.00635*	0.00138	-0.001301*	0.000325
Red spruce (*Picea rubens* Sarg.)	0.0	0.0	-0.000302*	0.000107
White pine (*Pinus* spp.)	0.0	0.0	0.000605*	0.000169
Northern white-cedar (*Thuja occidentalis* L.)	0.0	0.0	0.000888*	0.000192
Hemlock (*Tsuga* spp.)	0.0	0.0	0.000391*	0.000071
Other softwoods	0.00285	0.00372	0.0	0.0
Hardwoods:				
Red maple (*Acer rubrum* L.)	0.0	0.0	0.000530*	0.000106
Sugar maple (*Acer saccharum* Marsh.)	0.0	0.0	0.000406*	0.000054
Yellow birch (*Betula alleghaniensis* Britton)	0.0	0.0	0.000391*	0.000113
Paper birch (*Betula papyrifera* Marsh.)	0.00041	0.00477	0.0	0.0
Beech (*Fagus* spp.)	0.0	0.0	0.000419*	0.000106
Ash (*Fraxinus* spp.)	0.0	0.0	0.000889*	0.000191
Hophornbeam (*Ostyra* spp.)	0.00132	0.00419	0.0	0.0
Bigtooth aspen (*Populus grandidentata* Michx.	0.00319*	0.00639	0.0	0.0
Quaking aspen (*Populus tresuloides* Michx.	0.00120	0.00827	0.0	0.0
Black cherry (*Prunus serotina* Ehrh.	0.0	0.0	0.001237*	0.000247
Red oak (*Quercus* spp.)	0.0	0.0	0.000883*	0.000106
Other hardwoods	0.00125	0.00603	0.0	0.0

*Value differs significantly from 0. The critical probability value for 19 simultaneous tests is 0.006.

[1]Model form is: $d = a + b(D_2-5)$

where:

d = difference in average annual basal area growth (in ft^2/year)

D_2 = diameter at breast height (in inches) at beginning of measurement period two

a,b = weighted least-squares estimates with weights $(1/D_2-5)$